AD-778 007

AN INVESTIGATION OF THE TOWING CHARACTERISTICS OF THE DEEP SUBMERGENCE RESCUE VEHICLE (DSRV). PART II. SURFACE TOWING IN CALM WATER

Charles W. Sieber, et al

Naval Ship Research and Development Center
Bethesda, Maryland

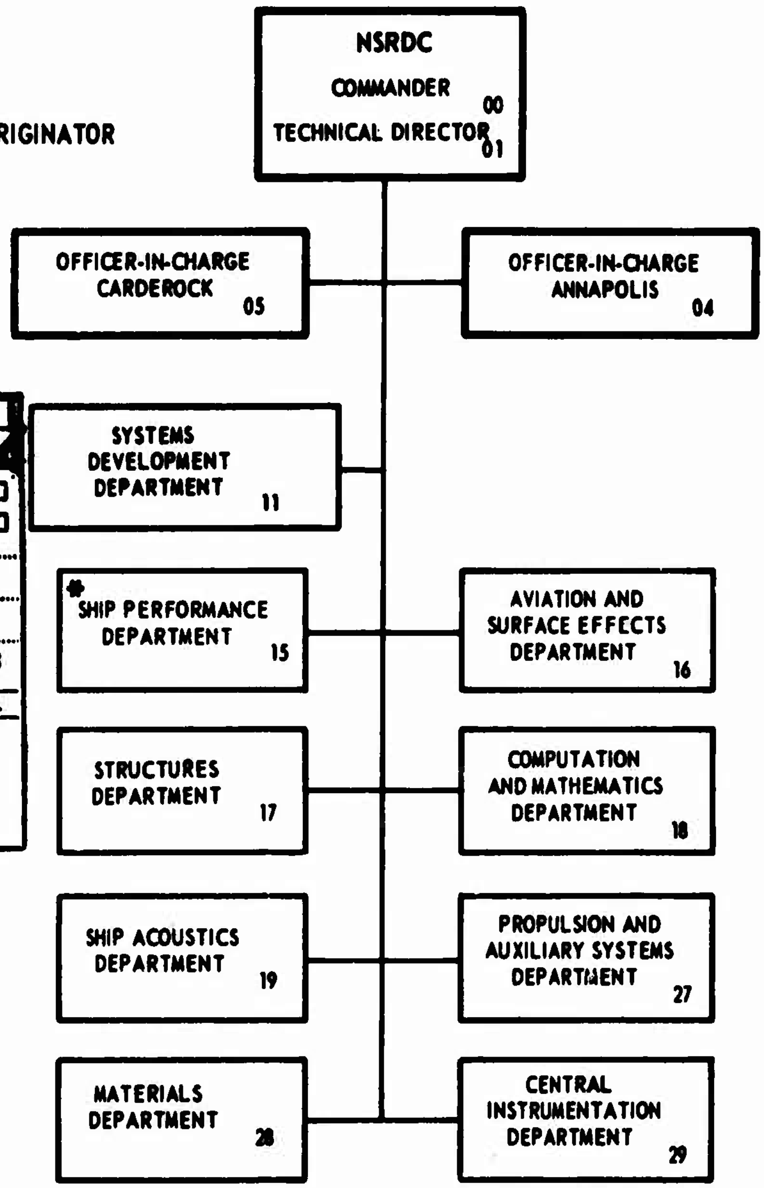
March 1974

The Naval Ship Research and Development Center is a U. S. Navy center for laboratory effort directed at achieving improved sea and air vehicles. It was formed in March 1967 by merging the David Taylor Model Basin at Carderock, Maryland with the Marine Engineering Laboratory at Annapolis, Maryland.

Naval Ship Research and Development Center
Bethesda, Md. 20034

MAJOR NSRDC ORGANIZATIONAL COMPONENTS

*REPORT ORIGINATOR



ACCESSION for
NTIS White Section ☑
DDC Buff Section ☐
UNANNOUNCED ☐
JUSTIFICATION ....

BY ....
DISTRIBUTION/AVAILABILITY CODES

Dist.	AVAIL. and/or SPECIAL	
A		

NDW-NSRDC 3960/43b (Rev. 3-72)
GPO 928-108

DEPARTMENT OF THE NAVY

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

BETHESDA, MARYLAND 20034

AN INVESTIGATION OF THE TOWING CHARACTERISTICS OF THE DEEP SUBMERGENCE RESCUE VEHICLE (DSRV)

PART II – SURFACE TOWING IN CALM WATER

by

Charles W. Sieber

R. Knutson

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

March 1974

Report 4146

ib

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

AD778007

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Ship Research and Development Center Bethesda, Maryland 20034	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
AN INVESTIGATION OF THE TOWING CHARACTERISTICS OF THE DEEP SUBMERGENCE RESCUE VEHICLE (DSRV)
PART II – SURFACE TOWING IN CALM WATER

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Research and Development Report

5. AUTHOR(S) (First name, middle initial, last name)
Charles W. Sieber and R. Knutson

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1974	38	4

8a. CONTRACT OR GRANT NO. b. PROJECT NO. NAVSEC Work Request WR-1-6120 c. NAVSHIPS Project Order 1-0269 NSRDC Work Unit 1548-704 d.	9a. ORIGINATOR'S REPORT NUMBER(S) 4146 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Ship Systems Command Washington, D.C.

13. ABSTRACT

The surface towing characteristics of the Deep Submergence Rescue Vehicle (DSRV) are examined for a variety of towpoints and ballast conditions. The results indicate that the DSRV may with care be successfully towed on the surface at speeds up to 3.3 knots. Using towpoints located on the forward hard ring, vehicle net buoyancies from 130 to 2730 pounds may be employed. Care must be exercised to avoid the regimes of lateral divergence and spontaneous submergence, the boundaries of each being defined.

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Towed Systems						
Submarine Towing						
Submarine Rescue						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

ia

UNCLASSIFIED
Security Classification

NOTATION

B	Total buoyancy of the hull envelope
I_x	Real moment of inertia in roll
I_y	Real moment of inertia in pitch
K	Rolling moment
$K_{\dot{p}}$	Added hydrodynamic moment of inertia in roll
$M_{\dot{q}}$	Added hydrodynamic moment of inertia in pitch
T_θ	Natural period of oscillation in pitch
T_ϕ	Natural period of oscillation in roll
W	Total weight including entrained water
Z_B	Vertical location of the centroid of the hull envelope
Z_G	Vertical location of the center of total mass
λ	Linear scale ratio
ρ_m	Fluid density for model
ρ_p	Fluid density for prototype
ϕ	Angle of roll

ABSTRACT

The surface towing characteristics of the Deep Submergence Rescue Vehicle (DSRV) are examined for a variety of towpoints and ballast conditions. The results indicate that the DSRV may with care be successfully towed on the surface at speeds up to 3.3 knots. Using towpoints located on the forward hard ring, vehicle net buoyancies from 130 to 2730 pounds may be employed. Care must be exercised to avoid the regimes of lateral divergence and spontaneous submergence, the boundaries of each being defined.

ADMINISTRATIVE INFORMATION

This research was funded by the Naval Ship Systems Command (NAVSHIPS) under Naval Ship Engineering Center (NAVSEC) Work Request WR-i-6120 of 21 January 1971 and Naval Ship Systems Command Project Order 1-0269 of 28 June 1971, Naval Ship Research and Development Center (NSRDC) Work Unit 1548-704.

INTRODUCTION

At the request of the Naval Ship Systems Command, the Naval Ship Research and Development Center undertook a program to develop a contingency technique for towing the Deep Submergence Rescue Vehicle (DSRV) at high speed with a ship-of-opportunity. The DSRV is a small air-transportable submersible primarily designed to rescue personnel from a disabled submarine and transfer them to another submarine or to the surface. It is envisioned that circumstances might arise in which a specialized support ship would not be immediately available, making it necessary to employ a more or less unequipped ship-of-opportunity. Such a mission could involve both deep-water submerged towing, which was treated earlier,[1] and surface towing in harbors and other shallow areas.

This report deals strictly with the aspect of surface towing in calm water. Basic operational considerations for accomplishing a tow are discussed; the prototype, the models,

---

[1] Sieber, C.W. and R. Knutson, "An Investigation of the Towing Characteristics of the Deep Submergence Rescue Vehicle (DSRV) – Part I Submerged Towing in Calm Water," Naval Ship Research and Development Center Report 4145 (in preparation). A complete listing of references is given on page 29.

the associated experimental equipment and instrumentation, and the procedures that were used in the experimental investigations are described; and the results of these investigations, including data for both steady-state conditions and transient behavior, are presented.

OPERATIONAL CONSIDERATIONS AND RESTRICTIONS

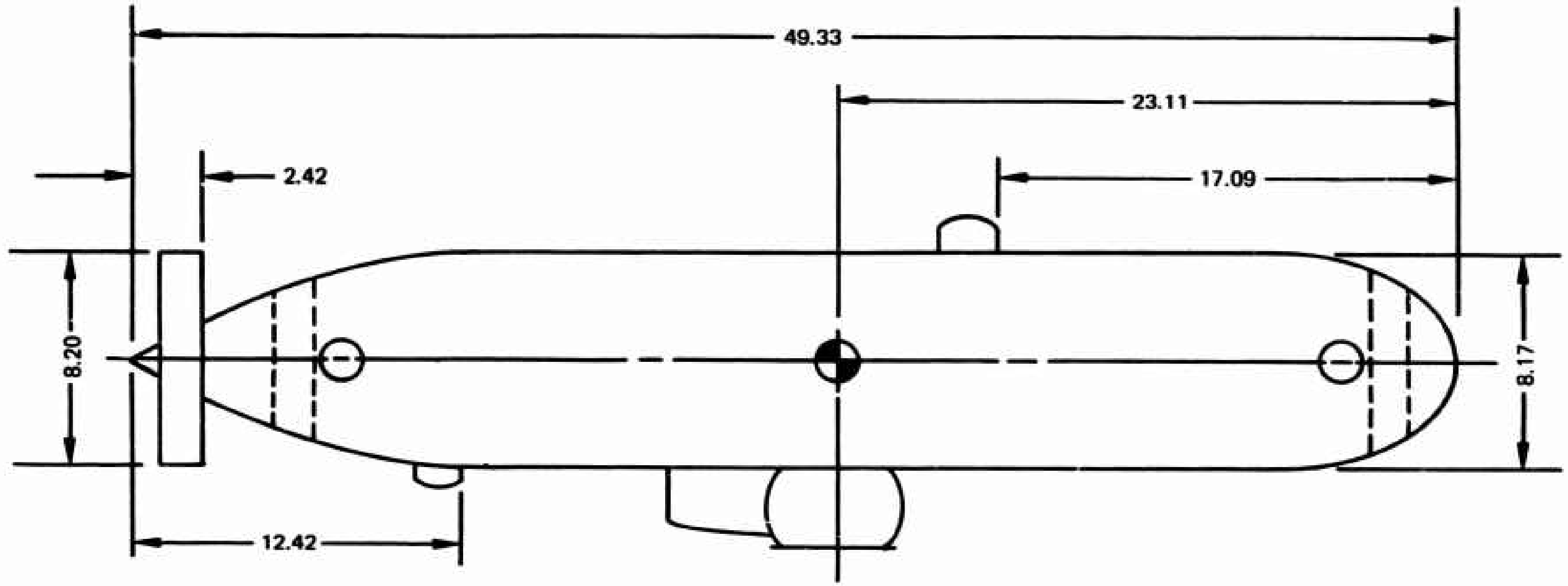
There were several basic operational considerations and restrictions imposed in the development of towing techniques. These are listed as follows:

1. The outer envelope of the DSRV is constructed of formed glass-reinforced plastic and is intended only for streamlining purposes. Any towing loads must be taken by two circumferential rings located fore and aft on the vehicle. The vehicle can be towed only from the existing light-alloy fittings protruding through the skin from these rings.
2. The towline(s) should not come in contact with the envelope due to the fragile nature of the glass-reinforced plastic.
3. In the interest of safety, the vehicle should be positively buoyant.
4. For simplicity and reliability, the use of additional bodies such as depressors, auxiliary surfaces, or appendages on the vehicle should be avoided.
5. The propeller should be freewheeling.
6. The shroud must be fixed in place, preferably at zero deflection so that the tow can be accomplished without crew.
7. Insofar as possible, the same towing conditions should be usable for both surfaced and submerged towing.

DESCRIPTION OF PROTOTYPE AND MODELS

The overall configuration of the prototype vehicle as represented for this investigation is shown by sketch in Figure 1. The basic hull is a body of revolution 49.33 feet in length and 8.17 feet in maximum diameter. The hull envelope contains forward and aft sets of vertical and horizontal thrusters which provide control for low-speed maneuvering. At the stern is an all-movable control shroud and a three-bladed-propeller for main propulsion. External to the envelope are the transfer skirt assembly (consisting of a mating skirt, a shock mitigation system, and a splitter plate) located below the hull and two small fairings which house electronic components.

The vehicle is represented for experimentation by two models with different scale ratios. The first is NSRDC Model 5128, a 16.44-foot-long, free-flooding, mahogany model



ALL DIMENSIONS ARE IN FEET

Figure 1 – DSRV Hull Geometry Showing Principal Full-Scale Dimensions

geometrically scaled from the prototype with a linear ratio of 3. Propellers in the thruster ducts are omitted. This model is shown in Figures 2 through 4 after minor modifications for towing were incorporated. The second model, designated NSRDC Model 5200, is a 2.32-foot-long mahogany model with a linear scale ratio of 21.28. Propellers are omitted from the thruster ducts in this model as well. Model 5200 is shown in Figures 5 through 7.

Detailed geometrical characteristics of the prototype and the models are presented in Table 1.

MODEL PREPARATIONS

The following modifications and preparations were performed on the models:

MODEL 5128

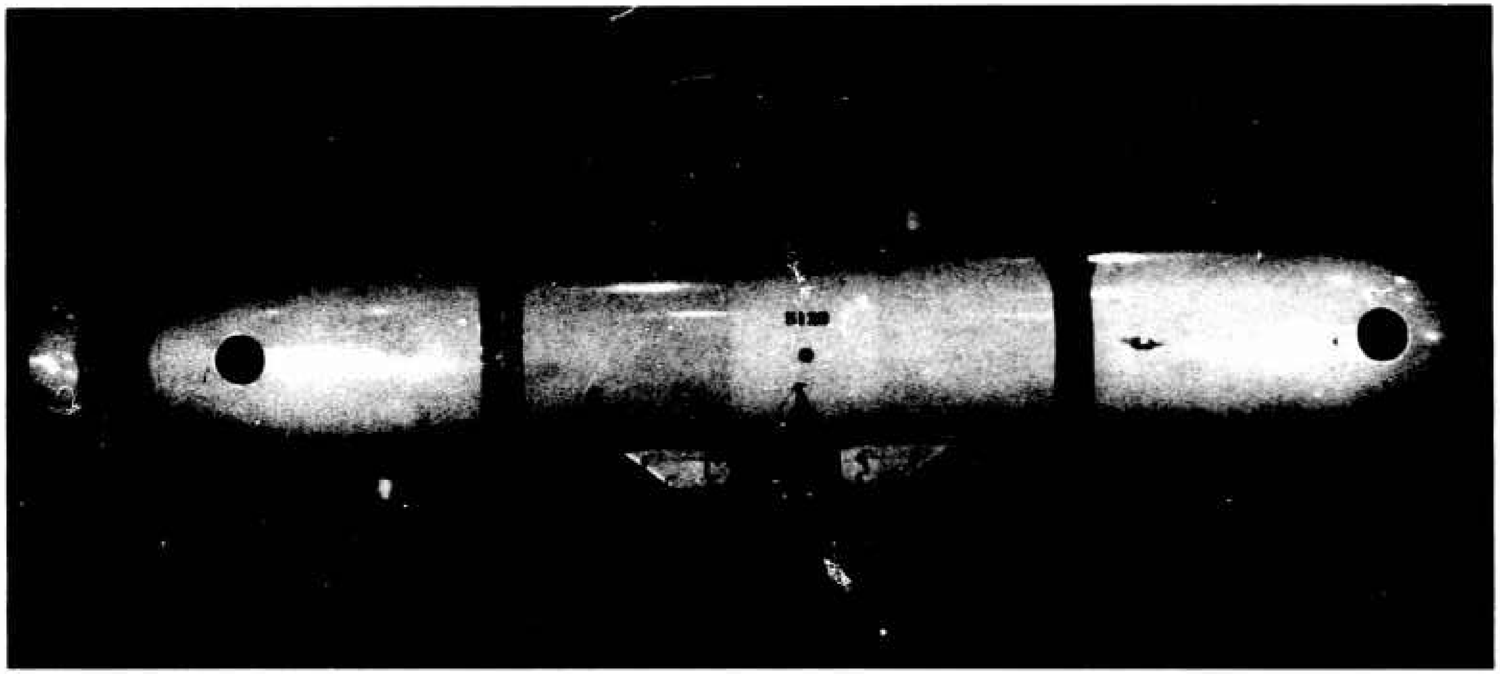
1. The splitter plate behind the mating skirt was altered to a length corresponding to that currently fitted to the prototype.
2. The vertical and horizontal positions of the shroud were locked at angles of incidence of zero degrees.
3. At the station of the forward hard ring (located approximately 12 feet aft of the forward perpendicular on the prototype) towpoints were installed at locations corresponding to the lifting eyes; this location is detailed in Figure 8. Considerable internal structure was added to withstand the loads expected on these towpoints.

MODEL 5200

1. The model was converted to a free-flooding condition to facilitate frequent and rapid changes in ballast.
2. A freewheeling stern propeller which approximated the prototype propeller was installed.
3. Towpoints were installed at locations corresponding to the forward lifting eyes and the forward ASR capture arms. These locations are detailed in Figure 8.
4. A sand strip to stimulate boundary layer turbulence was installed around the nose of the body at a station corresponding to the location of the sand strip on Model 5128, which is 2.0 feet aft of the forward perpendicular on the prototype.

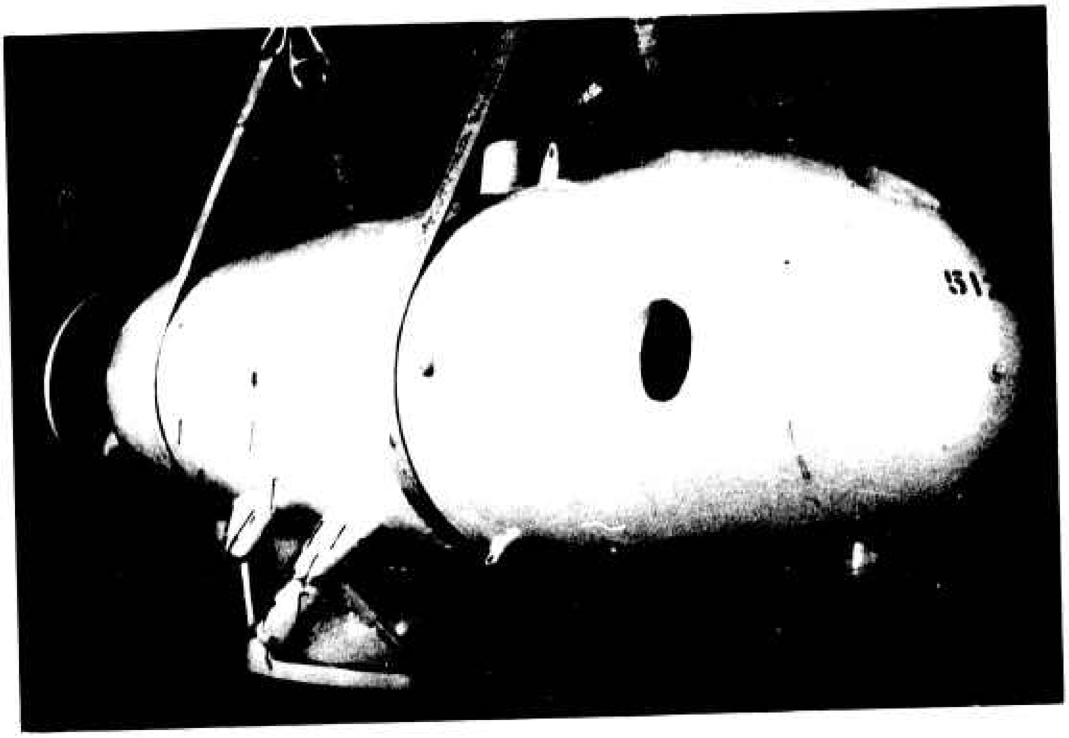
MODEL BALLASTING PROCEDURES

The ballasting procedures, all of which were conducted with the models flooded and fully submerged in water, are outlined below:



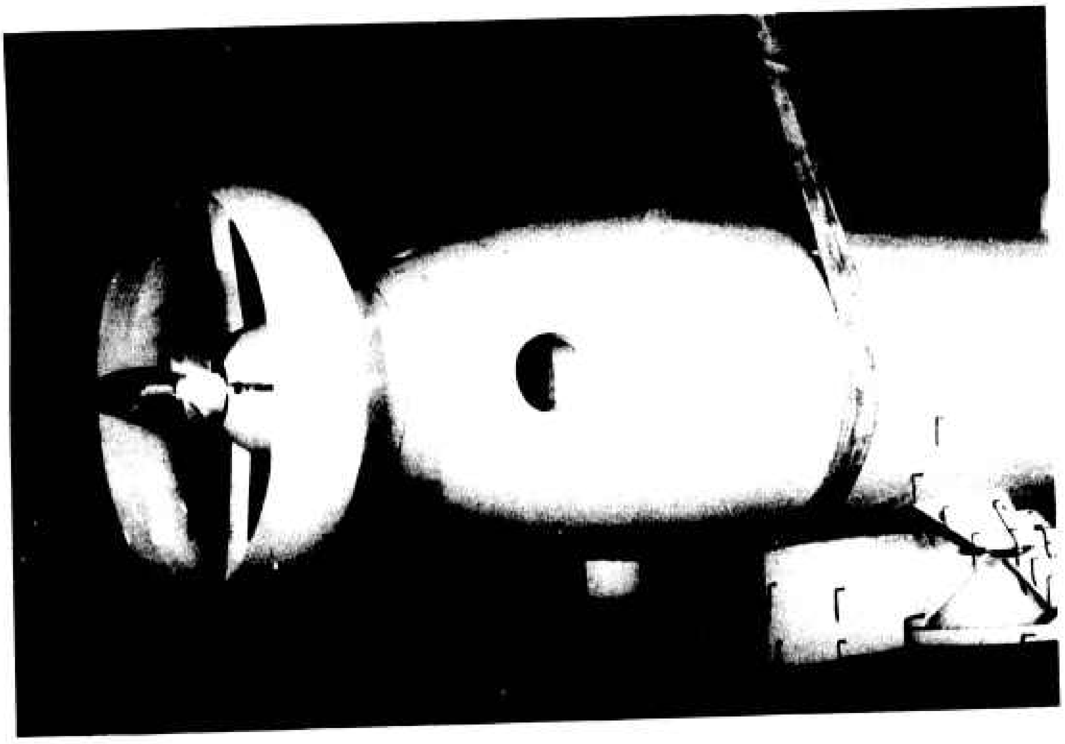
PSD 331958

Figure 2 – Profile View of DSRV Model 5128



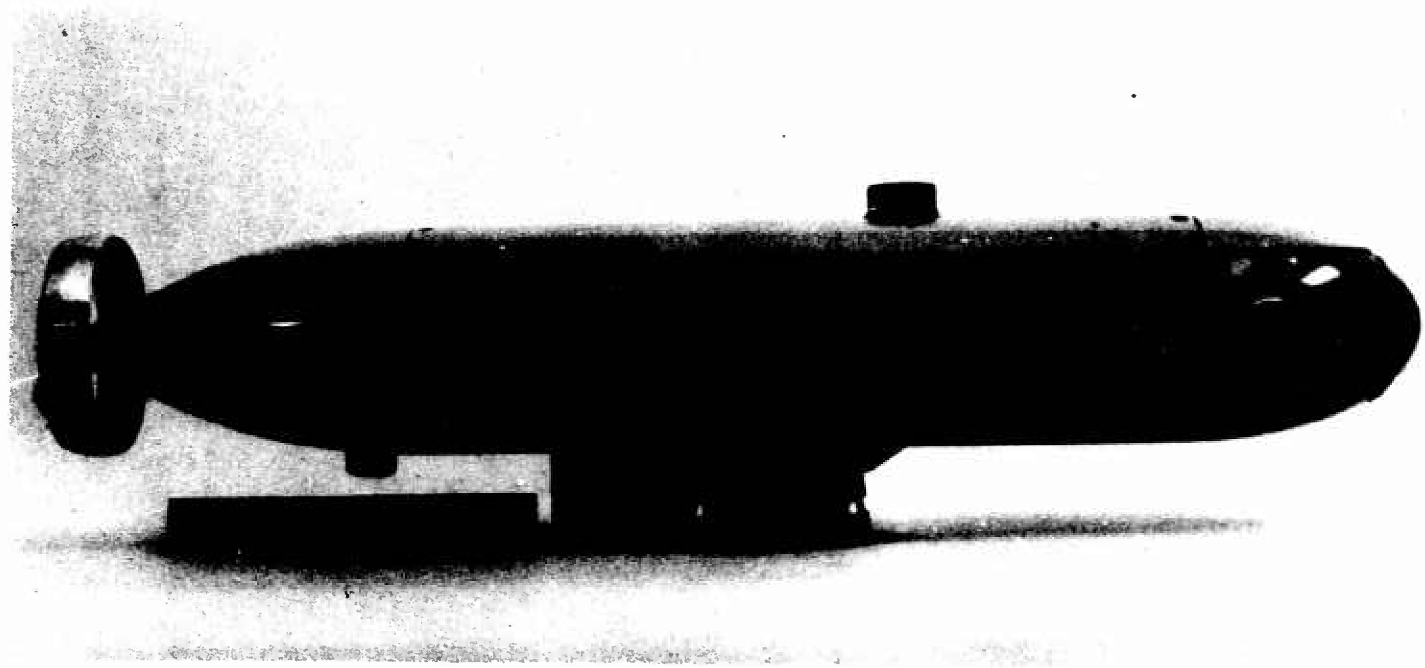
PSD 331960

Figure 3 – Starboard Bow View of DSRV Model 5128



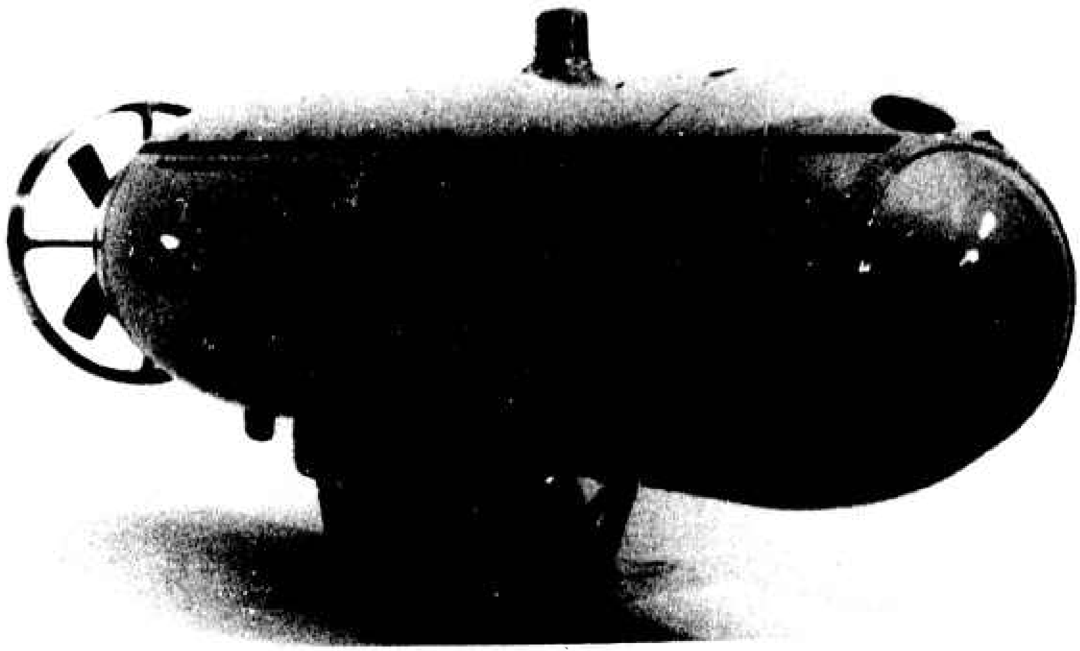
PSD 331961

Figure 4 – Starboard Quarter View of DSRV Model 5128



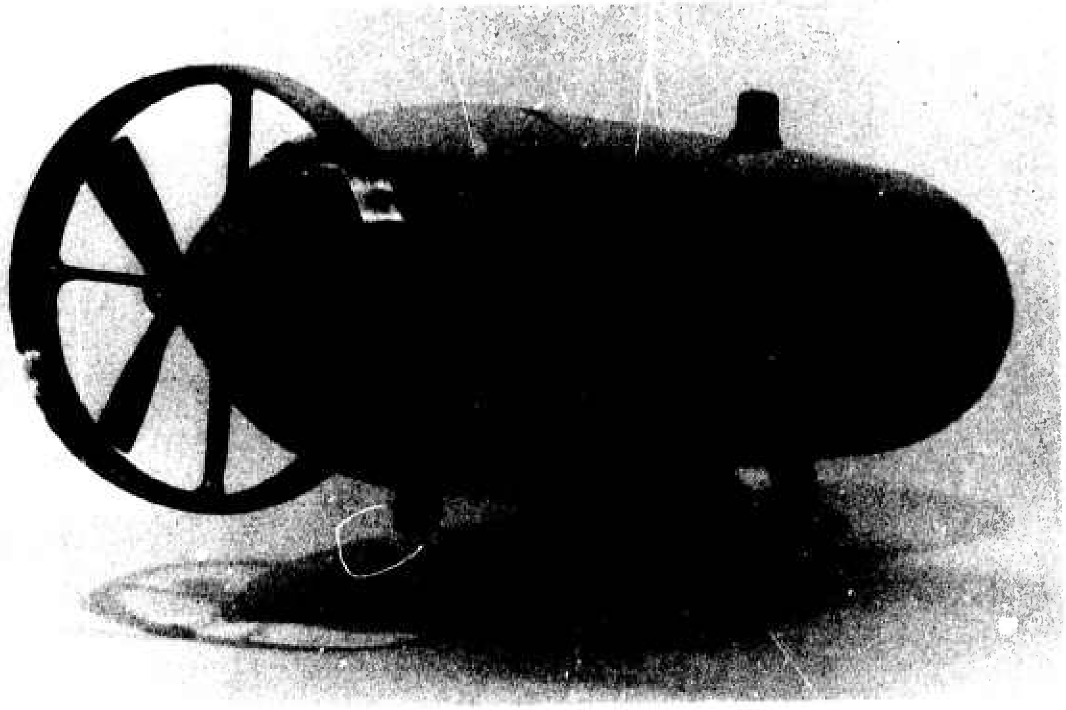
PSD 332542

Figure 5 – Profile View of DSRV Model 5200



PSD 332543

Figure 6 – Starboard Bow View of DSRV Model 5200



PSD 332544

Figure 7 – Starboard Quarter View of DSRV Model 5200

TABLE 1 – GEOMETRIC CHARACTERISTICS OF THE DSRV PROTOTYPE AND MODELS

	Prototype	Model 5128	Model 5200
General Characteristics			
Linear Scale Ratio	1.00	3.00	21.28
Overall Length, feet	49.33	16.44	2.32
Maximum Beam, feet	8.17	2.72	0.38
Wetted Surface Area, square feet	1318.2	146.46	2.91
Volume of Hull Envelope, cubic feet	2184.5	80.91	0.27
Longitudinal Distance to Centroid of Hull Envelope from Forward Perpendicular, feet	23.11	7.70	1.09
Height of Centroid of Hull Envelope Above Baseline, feet	3.92	1.30	0.18
Stern Shroud			
Maximum Diameter, feet	8.20	2.73	0.39
Section Chord, feet	1.83	0.61	0.09
Planform Area, square feet	14.62	1.62	0.03
Aspect Ratio	4.33	4.33	4.33
Section Chord Angle, degrees	3.5	3.5	3.5
NACA Section Profile (minus 8.33 percent at trailing edge)	0015	0015	0015
Longitudinal Distance to Leading Edge from Aft Perpendicular, feet	2.42	0.81	0.11
Stern Propeller		Model 4280	
Diameter, feet	6.00	2.00	0.28
Number of Blades	3	3	3
Blade Rake Angle, degrees	17.72	17.72	0
Pitch Ratio at 0.7 Radius	0.93	0.93	0.40

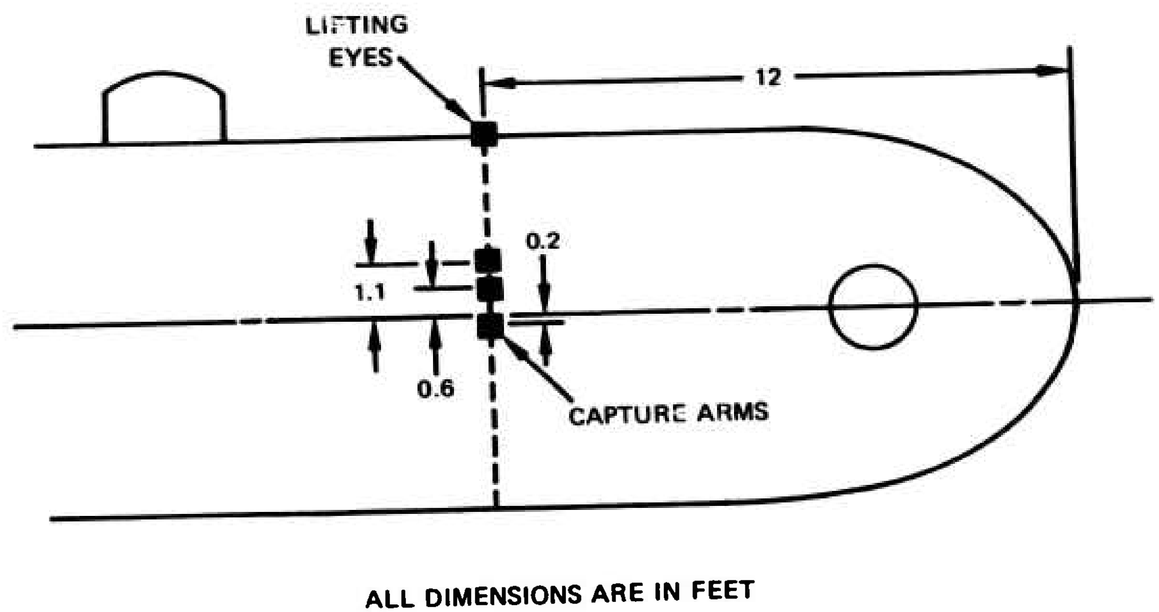


Figure 8 — Side View Showing Effective Full-Scale Locations of the Towpoints on the Forward Hard Ring

MODEL 5128

1. The model was ballasted initially to a net positive buoyancy condition corresponding to approximately 250 pounds full-scale.

2 With this weight condition, the static roll and pitch trims were set to angles of zero degrees by adjustment of the lateral and longitudinal ballast locations.

3. A known static rolling moment was applied about the centroid of the hull envelope, and the resulting angle of roll was measured. Using the relationship,[2]

$$K = (Z_G W - Z_B B) \sin \phi \qquad (1)$$

the center of total mass of the model was adjusted to coincide with that of the prototype.

4. The model then was oscillated freely in roll and pitch, and the resulting periods of oscillation were recorded. These data were used to determine the moments of inertia in roll and pitch from the relationships[3]

$$T_\phi \cong 2\pi \left[(I_x - K_{\dot{p}})/(Z_G W - Z_B B)\right]^{1/2} \qquad (2)$$

and

$$T_\theta \cong 2\pi \left[(I_y - M_{\dot{q}})/(Z_G W - Z_B B)\right]^{1/2} \qquad (3)$$

The values of $K_{\dot{p}}$ and $M_{\dot{q}}$ in Equations (2) and (3) were obtained from experimental data contained in Reference 4.

The moment of inertia in yaw, while not specifically determined, can be assumed to be very near that in pitch. This assumption is considered valid since the vehicle is essentially axially symmetric, especially near the ends, and the center of total mass is near the axis.

MODEL 5200

Model 5200 was ballasted using similar procedures but with an initial net positive buoyancy corresponding to approximately 260 pounds full-scale. Provision was made to allow the buoyancy to be varied through a range from 260 to 2730 pounds full-scale. Level static roll and pitch trims were maintained across this buoyancy range.

---

[2] Imlay, Frederick H., "Complete Expressions for the Gravitational and Buoyancy Force Terms in the Equations of Motion of a Submerged Body," David Taylor Model Basin Report 1845 (Jun 1964).

[3] Gertler, Morton and Grant R. Hagen, "Standard Equations of Motions for Submarine Simulation," Naval Ship Research and Development Center Report 2510 (Jun 1967).

[4] Young, D.C., "Model Investigation of the Stability and Control Characteristics of the Contract Design for the Deep Submergence Rescue Vehicle," Naval Ship Research and Development Center Report 3030 (Apr 1969).

Table 2 lists the ballast conditions and the inertial properties of the models and compares them to those of the prototype. Note that the inertial scaling was generally accurate except for the natural period of roll of Model 5128, where the techniques by which this model had been constructed limited the available moment of inertia in roll.

The effect on selected static and inertial parameters of variation in buoyancy for Model 5200 is shown in Figures 9 and 10.

EXPERIMENTAL EQUIPMENT AND INSTRUMENTATION

Previous investigations of submerged towing tensions, as well as basic handling considerations, suggested that a fiber rope towline of near-neutral buoyancy and an equivalent full-scale circumference of 6 to 8 inches would be a likely prototype choice. However, the assumption was made that for surface towing experiments the near-neutral buoyancy was an important parameter, while the precise towline diameter was not.

MODEL 5128

With the foregoing as a design rationale, the 1/3-scale towline and towing bridle were constructed of 7/16-inch-diameter double-braided nylon/polypropylene line. To protect the model, a weak link of 1/8-inch-diameter nylon cord with a breaking strength of 550 pounds was incorporated into the towline. The above-surface towing strut assembly used for these experiments was fabricated from aluminum alloy and designed to accept a maximum drag load of 600 pounds and a maximum lateral load of 100 pounds.

Instrumentation located at the towing strut consisted of angle potentiometers to measure vertical and horizontal cable angles and a ring-gauge dynamometer of 1200-pound-capacity to provide measurements of towing tension. The overall system accuracy for the angle potentiometers was ±1/2 degree; the ring dynamometer was accurate to ±6 pounds. Speed measurements with an accuracy of ±0.01 knot were obtained with a magnetic pickup on the towing carriage. Analog data readout was provided by an eight-channel pen recorder.

MODEL 5200

The towline selected for Model 5200 was a low-density 9-conductor electrical cable with an 0.087-inch diameter and nominal breaking strength of 100 pounds. The above-surface towing strut assembly used for experimentation with Model 5200 also was fabricated from aluminum alloy and was designed to accept a maximum drag or lateral load of 10 pounds. The strut could be varied in towing height from 0 to approximately 3 feet above the surface.

Instrumentation located at the towing strut consisted of angle potentiometers to measure vertical and horizontal cable angles and a ring-gauge dynamometer of 10-pound capacity to

TABLE 2 – BALLAST CONDITIONS AND INERTIAL PROPERTIES FOR THE DSRV PROTOTYPE AND MODELS

Ballast Conditions	Prototype	Scaling Factor	Model 5128*	Model 5200*
Total weight including entrained water, pounds**	139,769	$\rho_p/\rho_m\ \lambda^3$	5,036	14.12
Buoyancy of hull envelope, pounds	140,019	$\rho_p/\rho_m\ \lambda^3$	5,045	14.15
Net positive buoyancy, pounds**	250–260	$\rho_p/\rho_m\ \lambda^3$	9	0.03
Longitudinal distance to center of total mass from forward perpendicular, feet	23.11	λ	7.70	1.086
Height of center of total mass above baseline, feet	3.76	λ	1.25	0.177
Vertical distance between centroid of hull envelope and center of total mass, feet	0.15	λ	0.05	0.007
Moment to roll 1 degree, foot-pounds	354.3	$\rho_p/\rho_m\ \lambda^4$	4.4	0.00185
Inertial Properties				
Moment of inertia in roll, slugs–square feet	37,800	$\rho_p/\rho_m\ \lambda^5$	56	0.007
Moment of inertia in pitch, slugs–square feet	452,000	$\rho_p/\rho_m\ \lambda^5$	1,834	0.115
Moment of inertia in yaw, slugs–square feet	450,000	$\rho_p/\rho_m\ \lambda^5$	----	----
Natural submerged period of oscillation in roll, seconds	11.0	$\lambda^{1/2}$	5.0	2.2
Natural submerged period of oscillation in pitch, seconds	41.4	$\lambda^{1/2}$	24.0	9.0

*Experimentally determined.

**Reference condition for inertial experiments.

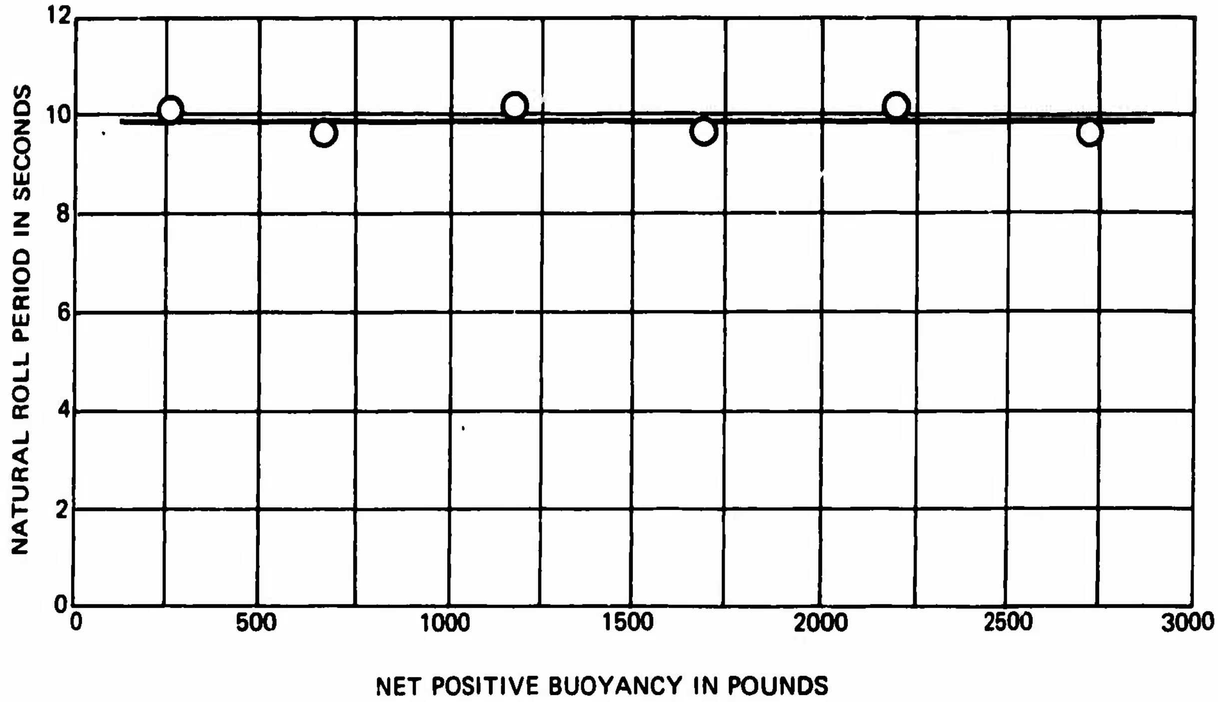


Figure 9 – Natural Roll Period as a Function of Buoyancy for the Full-Scale Vehicle as Represented by Model 5200

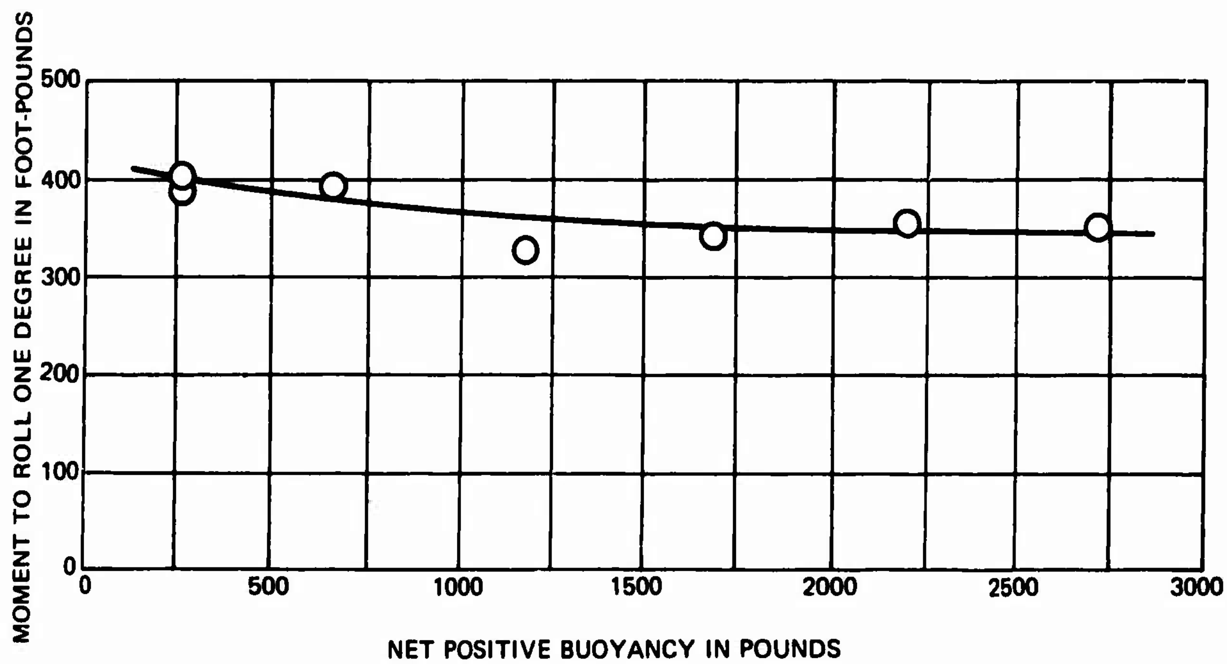


Figure 10 – Moment to Roll One Degree as a Function of Buoyancy for the Full-Scale Vehicle as Represented by Model 5200

provide measurement of towing tension. The overall system accuracy for the angle potentiometers was ±1/2 degree; the ring dynamometer was accurate to ±0.05 pound. The instrument package located within the model included a vertical-axis gyro capable of measuring pitch and roll of the model to an overall accuracy of ±1/2 degree. A second 10-pound-capacity ring-gauge dynamometer was incorporated into the towline at the apex of the towing bridle. This instrumentation is shown in Figures 11 and 12. Speed was measured and data were recorded by the same means as that used during investigations with Model 5128.

EXPERIMENTAL PROCEDURES

Very cursory surface towing with Model 5218 in conjunction with the earlier-reported[1] submerged calm-water towing had suggested the probability of lateral stability difficulties on the surface. With safety considerations in mind, the surface towing experiments were carried out primarily with Model 5200 in the high-speed basin. This scale ratio permitted the use of towlines corresponding to prototype lengths up to 108 feet without danger of collision with the basin walls.

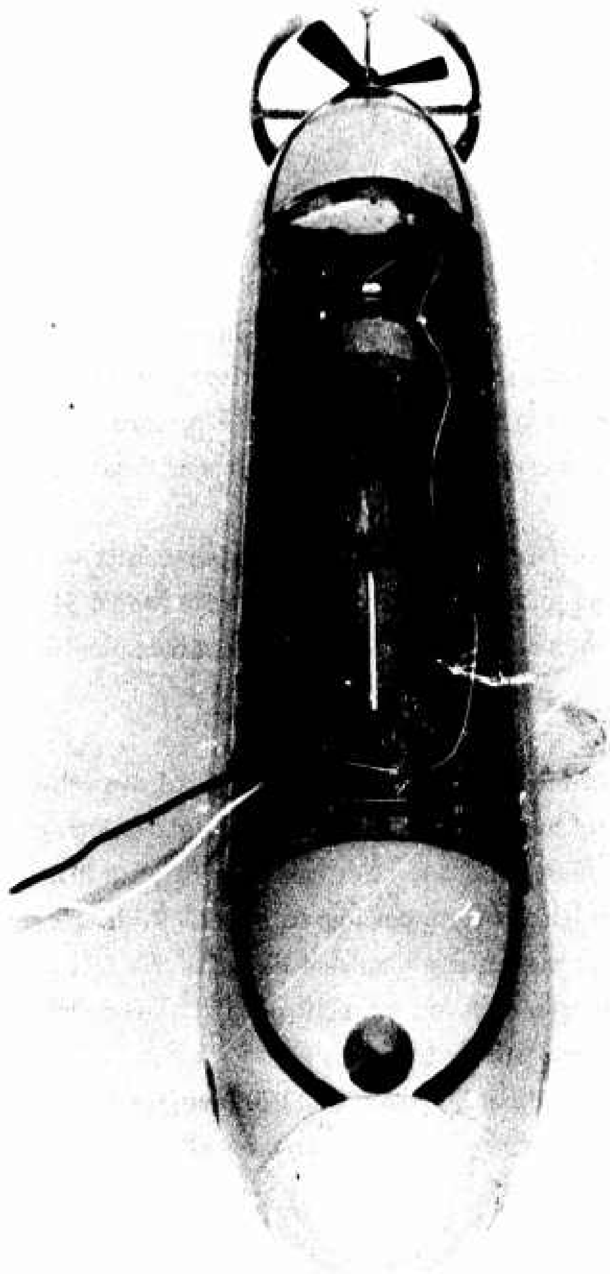
A shorter program of surface towing experiments subsequently was conducted using a towline length corresponding to approximately 110 feet with Model 5128 in the deep-water basin. This was primarily intended as a verification at Reynolds numbers nearer those of the prototype.

MODEL 5200

Towing performance of Model 5200 first was investigated through the range of positive buoyancies corresponding to 260 to 2730 pounds full-scale and the range of speeds up to 15 knots full-scale. All of these runs were made using the forward lifting eyes as towpoints and a simple bridle with leg lengths corresponding to 8 feet. Bridle geometry is shown in Figure 13. The towing strut was set at a simulated height of 9.8 feet above the water surface. For comparative purposes, each run was performed at towline lengths (including bridle) corresponding to 58 and 108 feet.

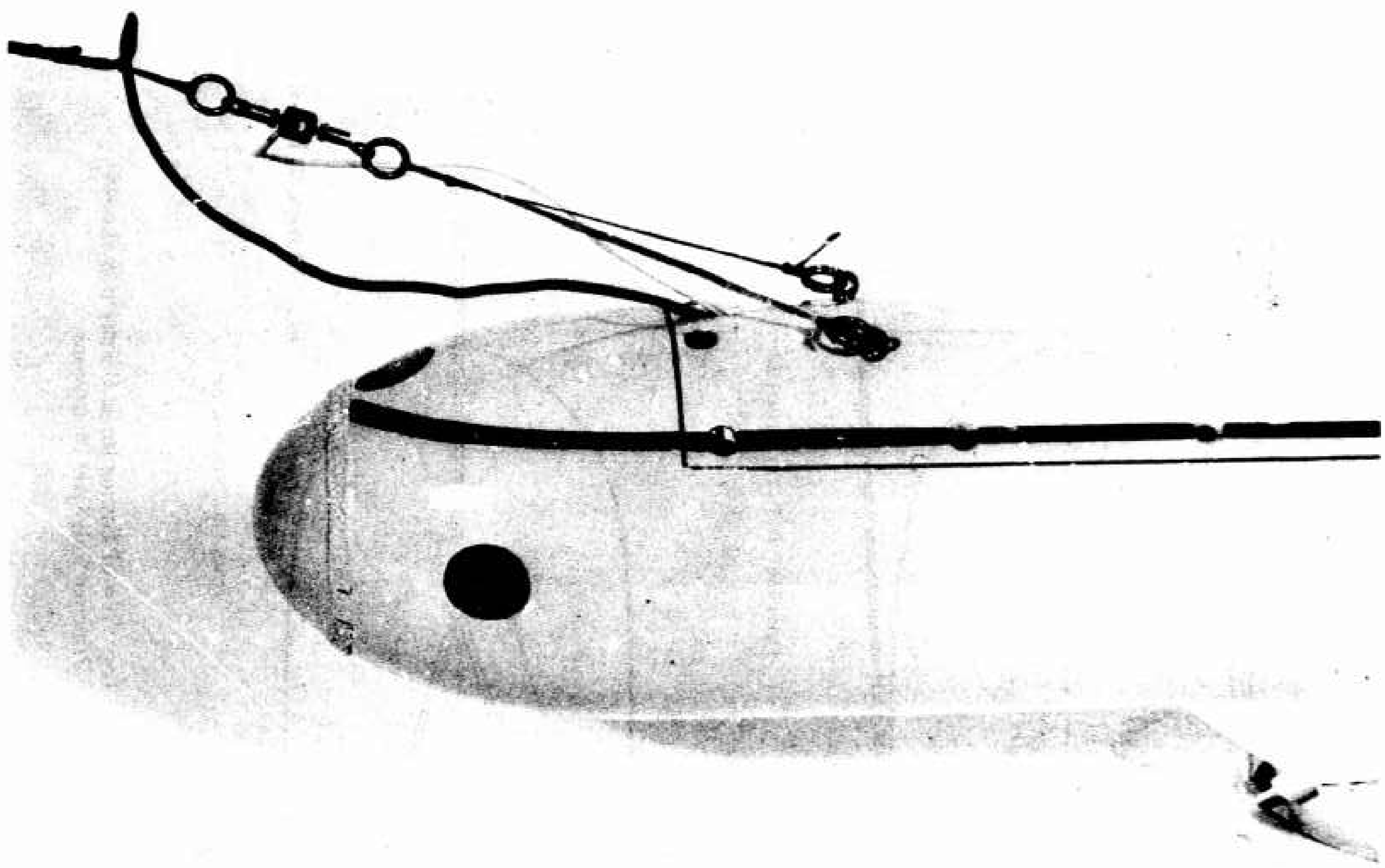
In addition, for a simulated net buoyancy of 1170 pounds, the effect of pure drag applied to the tail was investigated by means of two sizes of neutrally-buoyant drogues. The

[1] Ibid., pg. 1.



PSD 332540

Figure 11 – Looking Aft in DSRV Model 5200 Showing General Instrumentation Layout



PSD 332541

Figure 12 – Towing Bridle Rigged to Lifting-Eye Towpoint on DSRV Model 5200 Showing Position of Tension Link

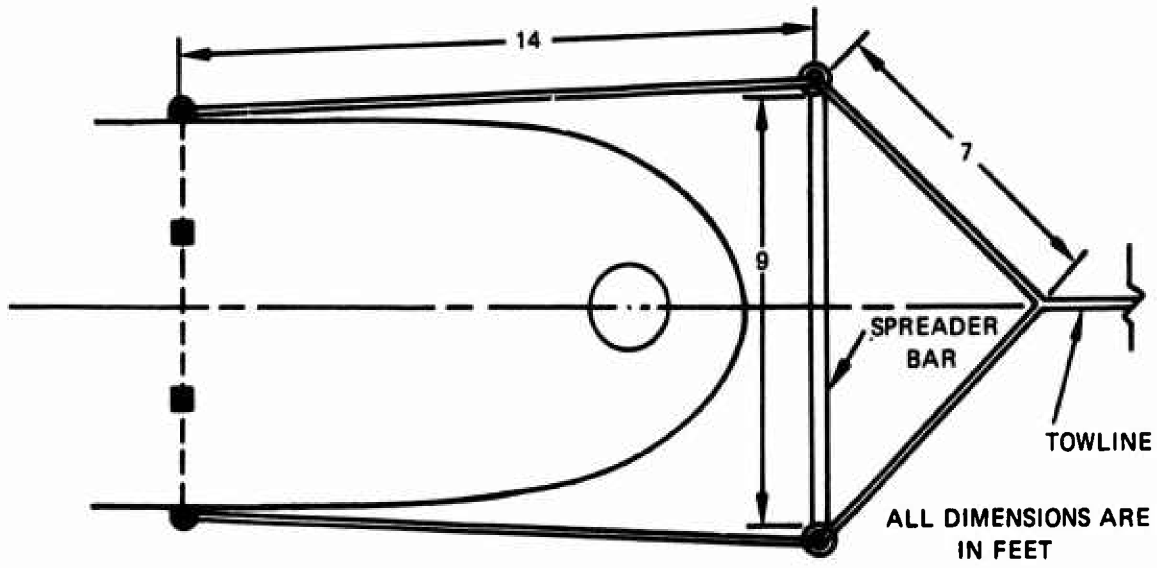


Figure 13a – Bridle with Spreader Bar

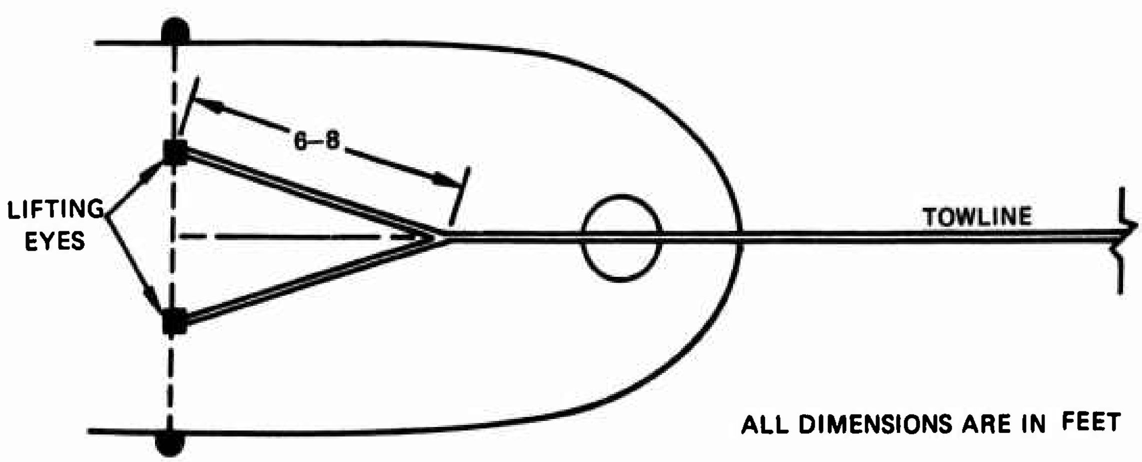


Figure 13b – Simple Bridle

Figure 13 – Top View of Towing Bridle Geometries Showing Principal Full-Scale Dimensions

drogues were towed from a bridle attached to the tail shroud support struts on line lengths simulating 50 feet. The drogues were sized to provide 40 percent and 100 percent of the steady-state drag of the model.

Also, a series of runs was made at a net buoyancy simulating 650 pounds using the forward capture arms as towpoints and a long bridle with spreader bar. The total bridle length simulated 20 feet full-scale and the overall towline length (including bridle) simulated 70 feet. This bridle geometry also is shown in Figure 13.

To investigate the effect on the towing performance of closing the open bottom of the mating skirt, representative runs were made with this closure accomplished by means of a semirigid polyethylene disc.

On all runs, lateral stability was investigated both by observing the spontaneous behavior of the model and by observing the behavior after disturbing the model to an angle of yaw by applying a lateral force to the shroud.

MODEL 5128

Towing performance of Model 5128 was investigated through the buoyancy range of 300 to 1135 pounds full-scale and the speed range to 5.1 knots full-scale. These experiments were carried out with simple bridles of lengths simulating 6 to 10 feet and total towline lengths (including bridle) simulating 111 to 115 feet. The towpoints at the forward lifting eyes were employed. The towing strut was set at a simulated height of 6.0 feet above the water surface. Also, the effect of sudden increases in towing tension due to carriage acceleration was investigated at a net buoyancy corresponding to 300 pounds full-scale.

RESULTS

For all conditions investigated, towing performance was very similar for the two models. Under no circumstances did the data from one scale ratio contradict the conclusions which could be drawn from the other. Where appropriate, therefore, the data from the two sets of experiments have been combined for presentation.

LATERAL STABILITY

The full-scale speed boundary which defines the upper envelope of dynamically stable surface towing is shown as a function of net positive buoyancy in Figure 14. Below this boundary, both models were stable in undisturbed towing and Model 5200 (the only model so investigated) exhibited stable response to all lateral-plane perturbations applied. This

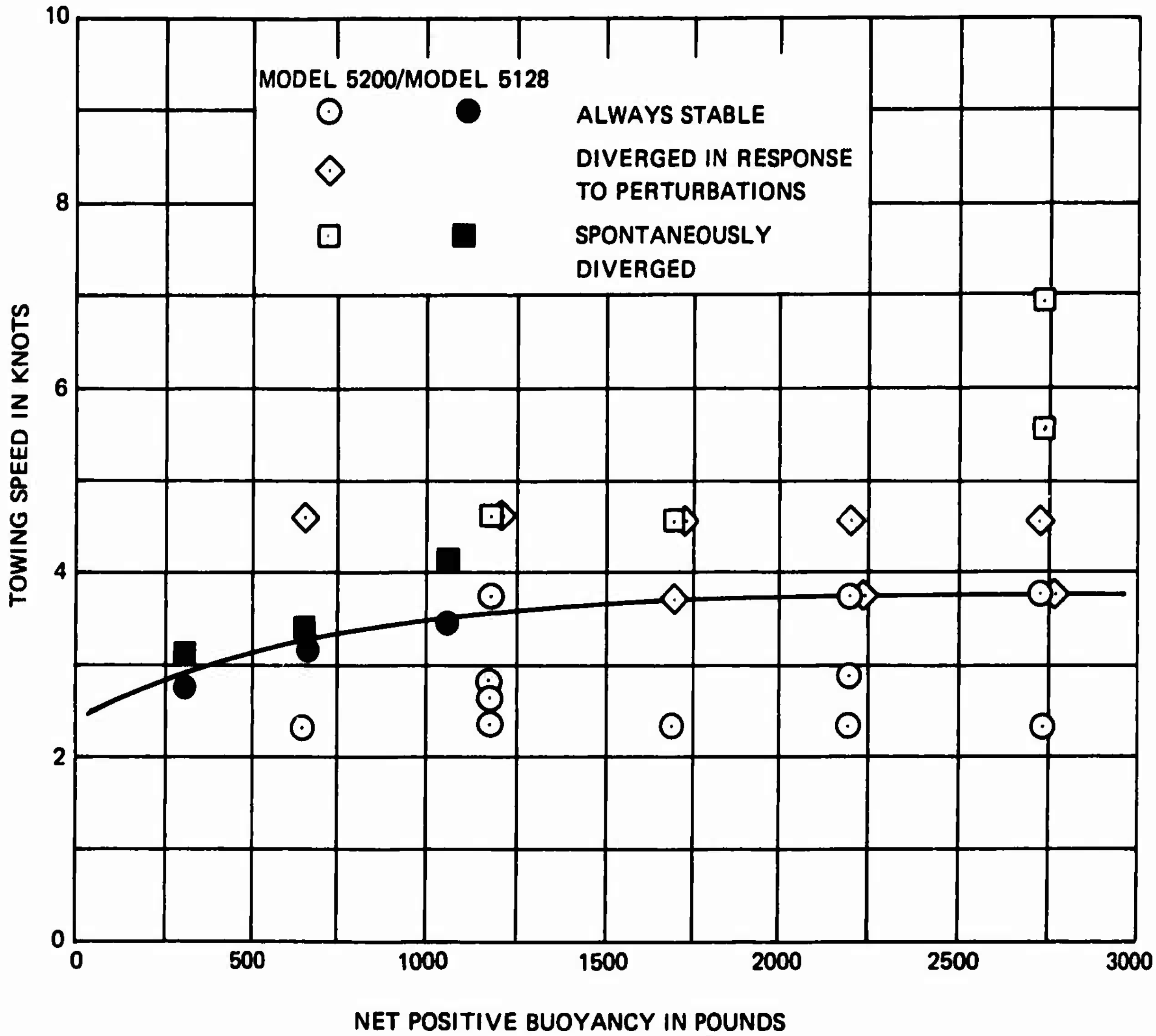


Figure 14 – Surface Towing Lateral-Plane Stability Showing Lower Boundary of Lateral Divergence Using the Lifting-Eye Towpoint

response, however, did involve (for large perturbations, i.e., input yaw angles of 20 to 30 degrees) transient excursions to trail angles as large as 40 to 50 degrees before returning to a nominal trail angle of zero degrees.

Above the boundary, the models began to exhibit a multistable type of behavior. This was characterized, either in response to a perturbation or (at a sufficiently high speed) spontaneously, by a slow lateral divergence to a large trail angle. Over a full-scale time period of approximately 60 seconds, the model would move out to a position resulting in a trail angle of 40 to 60 degrees, accompanied by a roll angle in the inboard direction of up to approximately 70 degrees. The outward motion of the model was smooth and steady at all times. With Model 5200, the complete course of this maneuver and the subsequent equilibrium condition could be observed, but with Model 5128 basin width restrictions forced the termination of a run soon after any strongly divergent tendency developed.

The lateral divergence appeared to be driven by the following mechanism: A slight yaw perturbation of the model would result in an inboard rolling moment being applied by the towline since the towpoints were located above the roll center. As soon as a roll angle was present, the drag of the mating skirt and the pitching moment applied by the towline combined to pitch the model outboard. This in turn increased the lateral forces on the model, thus increasing the divergence. The divergent behavior apparently depended on the towline rolling moment overcoming the static roll stability of the model.

When the towing speed was subsequently reduced to a value below the stability boundary, the model always recovered to a trail angle very near zero degrees.

SURFACE TOWING TENSION

Representative surface towing tension data for Model 5128 is presented as a function of towing speed in Figure 15. All data shown reflect the laterally undiverged condition. Corrections for scale effects have been made using standard techniques, with a correlation allowance coefficient of 0.0006 being applied. No measurable variation with buoyancy in surface towing tension was observed for either model.

Tension data for Model 5200 indicate that for the laterally diverged condition the steady-state surface towing tension is approximately twice what was measured for the undiverged case at a similar speed.

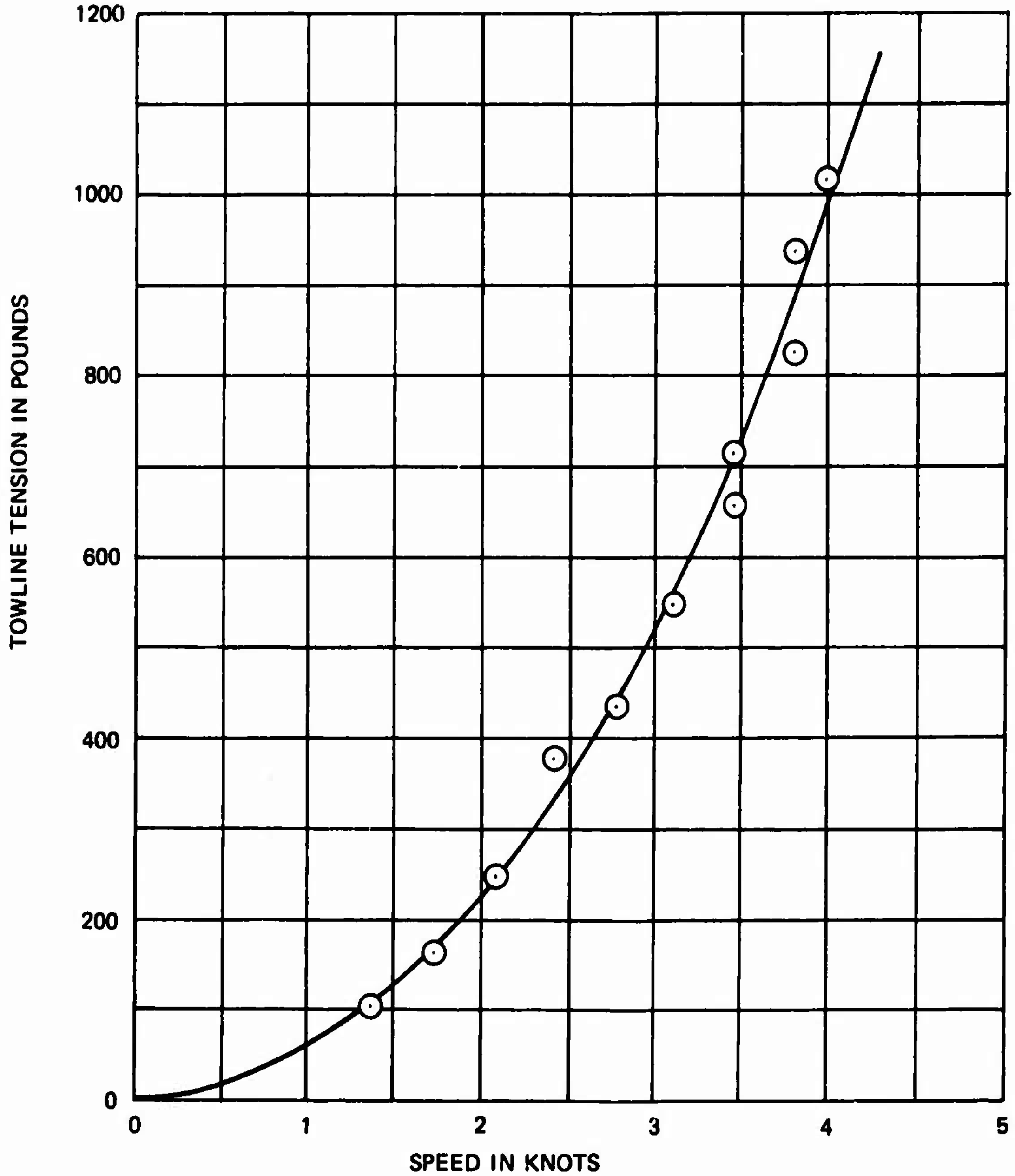


Figure 15 – Surface Towing Tension at Vehicle as a Function of Towing Speed Using the Lifting-Eye Towpoint

DEPARTURE FROM THE FREE SURFACE

The speed at which the vehicle leaves the free surface and spontaneously dives to a submerged running position is shown as a function of net positive buoyancy in Figure 16. With a modest acceleration, the model easily passes through the range of laterally unstable surface running before a divergence has time to develop. The behavior during the diving maneuver and the subsequent submerged towing performance have been previously investigated.[1]

Also of interest was the behavior when towing speed was backed down below the submergence speed boundary. Over a certain range of speeds below this boundary the vehicle would rise to a semisubmerged condition with a 20- to 25-degree nose-down pitch attitude and the tail shroud breaking the surface. Towing performance in this regime was stable, but small perturbations or further speed reduction would generally provoke a return to fully surfaced running. The occurrence of this semisubmerged running is also indicated in Figure 16.

For purposes of comparison, a data point is also indicated for the approximate submergence speed when using the capture arm towpoints. The sense of the curve through this point has been assumed to follow the lifting eye curve.

EFFECTS OF SUDDEN ACCELERATION

A moderate transient submergence followed by a slow return to semisubmerged running was induced by imposing an acceleration of approximately 2.7 feet/second/second up to a speed corresponding to approximately 0.5 knot below the spontaneous (quasi-steady-state) submergence speed. A temporary semisubmerged condition could be induced by similar acceleration up to a speed corresponding to approximately 1.1 knots below the quasi-steady-state submergence speed.

DECELERATION

As with any large streamlined mass, the vehicle will decelerate slowly when towing tension is removed and may present a not-inconsiderable danger to the towing ship. This

---

[1]Ibid., pg. 1.

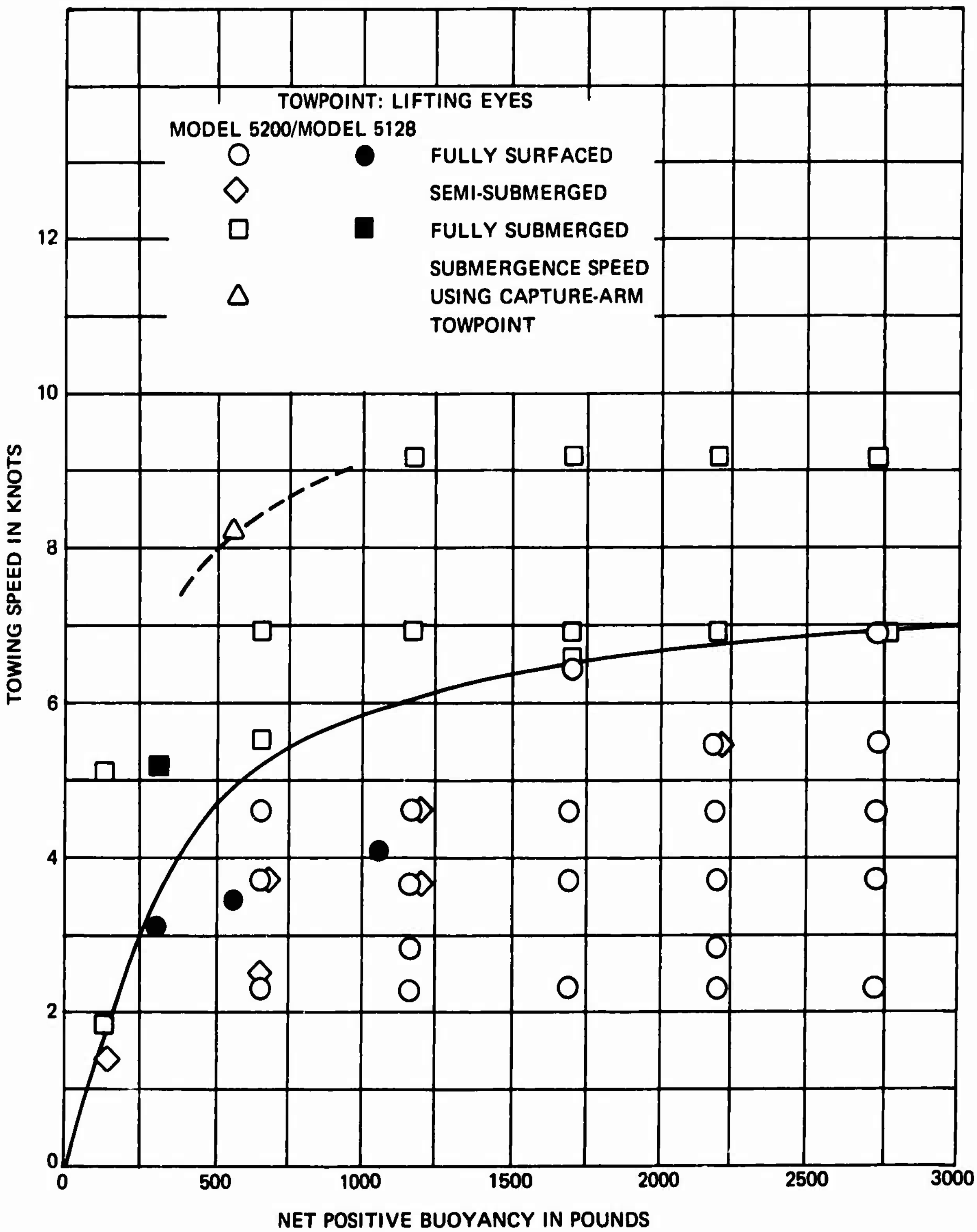


Figure 16 – Running Condition as a Function of Net Positive Buoyancy Showing Lower Boundary of Submerged Running Using the Lifting-Eye Towpoint

(Except as Noted)

characteristic is shown in Figure 17, which shows the coasting distance required to reach a nominal residual speed as a function of the original towing speed. This curve was generated by means of data taken from Reference 4 and extrapolated from Figure 15.

EFFECT OF DROGUES

The effect of drogue devices on surface towing performance is summarized by Figure 18. A slight increase in maximum stable surface towing speed is evidently available. Also shown in Figure 18 is the increase in submergence speed caused by drogues, a direct result of their inhibition of the pitch attitude required to break away from the free surface.

PERFORMANCE USING THE CAPTURE ARM TOWPOINTS

As indicated in Figure 16, use of the capture arm towpoints significantly raises the speed required for submergence. However, surface towing is accompanied by divergent tendencies similar to those encountered while towing from the lifting eyes. When such divergence begins, a bridle leg is immediately brought into contact with the hull. In the light of this unacceptable behavior and considering that the lifting eyes had already been found more satisfactory for submerged towing,[1] the capture arm towpoints were not investigated further.

INFLUENCE OF TOWLINE LENGTH

Within the range of towline lengths investigated, (58 to 115 feet full-scale) there was no apparent influence on surface towing performance.

---

[1]Ibid., pg. 1.

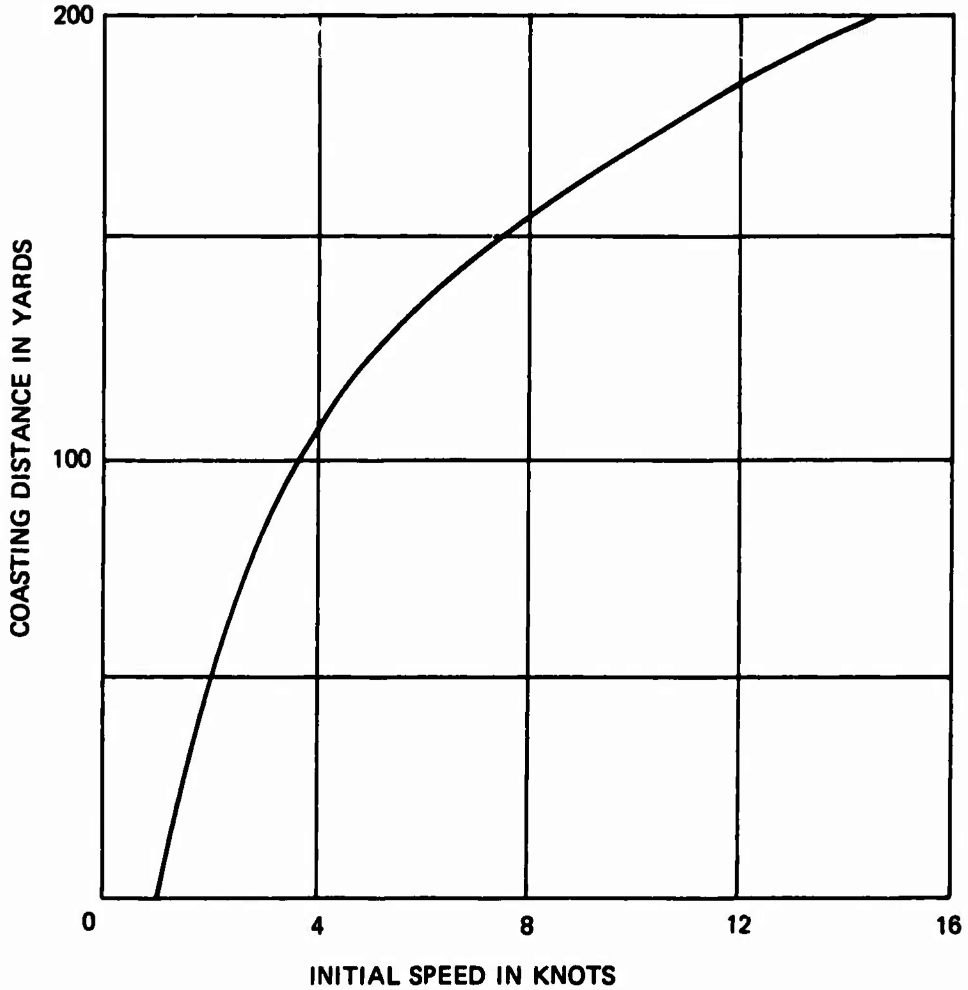


Figure 17 – Coasting Distance to Residual Speed of 0.5 Knots as a Function of Initial Speed

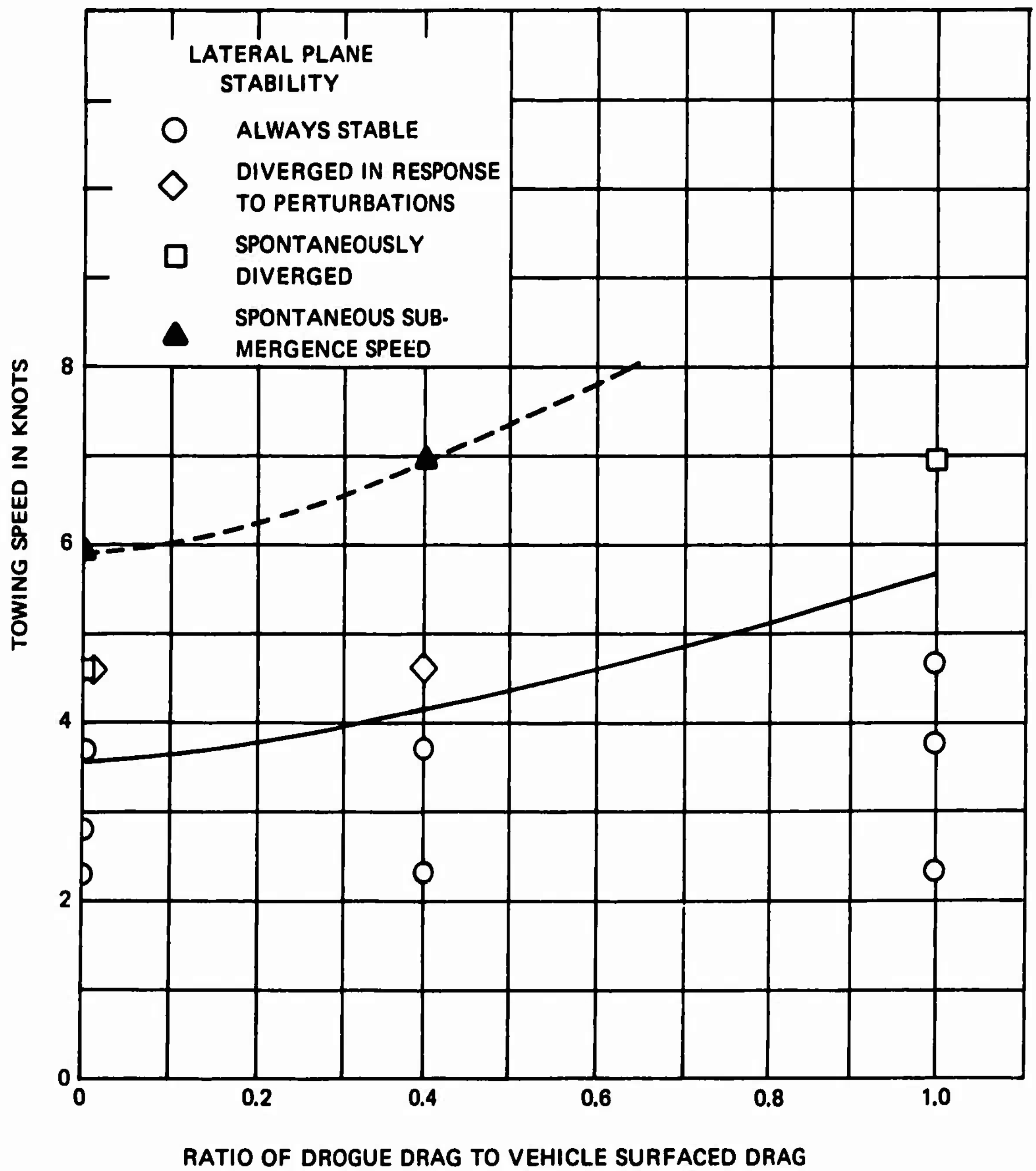


Figure 18 – Influence of Drogues on Surface Towing Performance Showing Lower Boundaries of Lateral Divergence and of Submergence
(Towpoint: Lifting Eyes; Buoyancy: 1170 pounds)

INFLUENCE OF THE MATING SKIRT CLOSURE PLATE

Closing the open bottom of the mating skirt had no detectable influence on any aspect of the towing performance.

CONCLUSIONS

1. Using the lifting eye towpoints and net positive buoyancies between 700 and 2600 pounds full-scale, the vehicle may be towed stably on the surface at speeds up to at least 3.3 knots.

2. As buoyancy is increased across this range, the speed at which the vehicle will spontaneously submerge increases from 5.0 to 6.7 knots.

3. In the course of accelerating to the speed at which submergence occurs, the vehicle will pass through a regime of moderate instability, characterized by a slow divergence to large trail angles. This does not in itself appear to be a dangerous situation; moreover, in the course of modest acceleration, the divergence will not have time to develop.

4. For smaller amounts of net positive buoyancy, the speed at which submergence occurs nearly coincides with the maximum stable surface speed. Therefore, the range of speeds of unstable surface running has been largely eliminated, to be replaced, in effect, by a range of submerged running. For a shallow-water tow, this may be undesirable since it increases the possibility of an inadvertant submergence.

5. The best buoyancy compromise among stable surface speed, shallow-water towing safety, and submerged towing performance appears to be approximately 1000 pounds positive.

6. The addition of drogues has the effect of raising both the maximum stable surface speed and the speed at which submergence occurs. In shallow water, a drogue would thus add a margin of safety, but it would require removal before attempting a submerged tow.

7. Based on the observations made earlier on the mechanism of the lateral divergence, it appears likely that any attempt to increase surface towing stability by means of appendages which happened to be located below the roll center would probably act to destabilize the vehicle by increasing the inboard rolling moment resulting from an initial yaw.

8. Also, DSRV as a towed vehicle on the surface will be very sluggish to turn or decelerate; sharp turns on the part of the towing ship will probably induce DSRV to track *well* outside the track of the towing ship. Selection of towline length for surface towing, therefore, should be governed by consideration of local traffic, waterway restrictions, and towing ship maneuvering room.

ACKNOWLEDGMENT

The authors would like to express their gratitude to Mr. William Sandberg of the Naval Ship Engineering Center for his assistance in locating prototype data. Credit for highly adaptive instrumentation design, especially in the case of the package developed for the small-scale Model 5200, goes to William VonFeldt of the Naval Ship Research and Development Center.

REFERENCES

1. Sieber, Charles W. and R. Knutson, "An Experimental Investigation of the Towing Characteristics of the Deep Submergence Rescue Vehicle (DSRV) – Part I Submerged Towing in Calm Water," Naval Ship Research and Development Center Report 4145.

2. Imlay, Frederick H., "Complete Expressions for the Gravitational and Buoyancy Force Terms in the Equations of Motion of a Submerged Body," David Taylor Model Basin Report 1845 (Jun 1964).

3. Gertler, Morton and Grant R. Hagen, "Standard Equations of Motion for Submarine Simulation," Naval Ship Research and Development Center Report 2510 (Jun 1967).

4. Young, D.B., "Model Investigation of the Stability and Control Characteristics of the Contract Design for the Deep Submergence Rescue Vehicle," Naval Ship Research and Development Center Report 3030 (Apr 1969).